





Running RHIC HI beyond 2017

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Thanks:
J. Nagle, D. Morrison,
W. Zajc, W. Horowitz,
B. Cole, J. Putschke,
S. Vigdor



What we have heard so far

- **STAR & PHENIX short term plans**
 - J. Dunlop & M. Leitch
- **STAR & PHENIX long term plans**
 - Z. Xu and D. Morrison
- **View of the PAC**
 - K. Rajagopal
- **Theoretical perspectives**
 - B. Muller and D. Kharzeev
- **Incredible amount of thinking and hard work going into future planning for this meetings!**



The charge

- **As we heard yesterday, we need to consider three epochs:**
 - **The short term: 2011-2017**
 - *Driven by current physics goals, and upcoming upgrades to STAR & PHENIX: Still needs compelling arguments*
 - **The medium term: 2017-2023...**
 - **The long term: 2023-**
 - *The EIC era: driven by new physics goals, discussed later today*
- **Steve Vigdor asked me to consider the case for physics in the medium term, independent of STAR & PHENIX plans**
 - Bias 1: The last several years of ATLAS skews my perspective towards high p_T physics.
 - Bias 2: The years before that were spent in PHOBOS, where my perspective was skewed to global physics & systematic studies



The medium term: 2017-2023

- **This world is as hard to predict in 2017 as 2011 would have been from from the perspective of 2005**
 - RHIC era was still in full steam
 - Ridge, mach cone, participant eccentricity (leading to v_n), direct photons, etc were all in embryonic state
 - η/s and AdS/CFT in the literature but were still not widely discussed
 - No-one had even tried measuring jets in RHIC experiments
 - LHC experiments were on the way, but were not central in people's thinking
- **By 2017, the LHC will be the 5.5 TeV gorilla**
 - Half energy p+Pb is under discussion for 2012 (lots of momentum!)
 - Full energy Pb+Pb should start in 2015
 - 2nd shutdown planned to upgrade luminosity



LHC Ion Plan to 2020+

		Year	System	Energy	Luminosity	
RHIC short term	{	2010	Pb+Pb	2.76 TeV	3.00E+25	1/2 energy
		2011	Pb+Pb (p+Pb MD)	2.76 TeV	1-1.5E25	
		2012	Pb+Pb OR p+Pb	2.76 (4.4) TeV	"maximum"	
		2013	shutdown (LS1)			full energy
		2014	shutdown (LS1)			
RHIC medium	{	2015	Pb+Pb	5.5 TeV	5.00E+26	
		2016	Pb+Pb	5.5 TeV	5.00E+26	
		2017	Pb+Pb OR p+Pb	5.5 (8.8) TeV		
		2018	shutdown (LS2)			
		2019	Pb+Pb	5.5 TeV	O(1E27)	full lumi
		2020	p+Pb OR d+Pb	8.8 (X) TeV		
		2021	Ar+Ar?			
		2022	shutdown (LS3)			

NB: nearly ~3 year gap in HI running from 2012-2015!



Does the LHC make RHIC obsolete?

- **LHC certainly brings a lot to the table**
 - 10x less luminosity than RHIC (for now), and short running times (and this is the “pre-Higgs” era), but high p_T rates far exceeding RHIC
- **Powerful suite of detectors**
 - ALICE
 - *A dedicated HI experiment with a complement of PID surrounding a very capable TPC*
 - *Nearly 1000 HI physicists excited to do physics with the detector*
 - ATLAS & CMS
 - *Excellent inner tracker out to $|\eta| < 2.5$*
 - *Finely-segmented calorimeters with EM & hadronic layers out to $|\eta| < 5$*
 - *Muon detection out to $|\eta| < 2.7$ (but low p_T cutoff)*
 - *Smaller working groups, but leveraging resources of huge collaborations*



Did RHIC make SPS obsolete?

- **No.**
- **Dual motivations: theory & experiment**
 - Experiment: SPS “landscape” physics
 - Theory: search for critical point
- **More interestingly, as new qualitative phenomena were discovered at RHIC, they were rediscovered at lower energies**
 - High p_T suppression revisited by WA98
 - Ridge and cone addressed by CERES data
- **As we found new things at RHIC, lots of interest in whether or not the SPS would “turn off” those effects**
 - And some things didn’t go away, e.g. “Mach cone” (a.k.a. v_n)
- **And now we are doing “SPS physics” at RHIC w/ BES**
 - And we are finding interesting agreement & discrepancies with older data



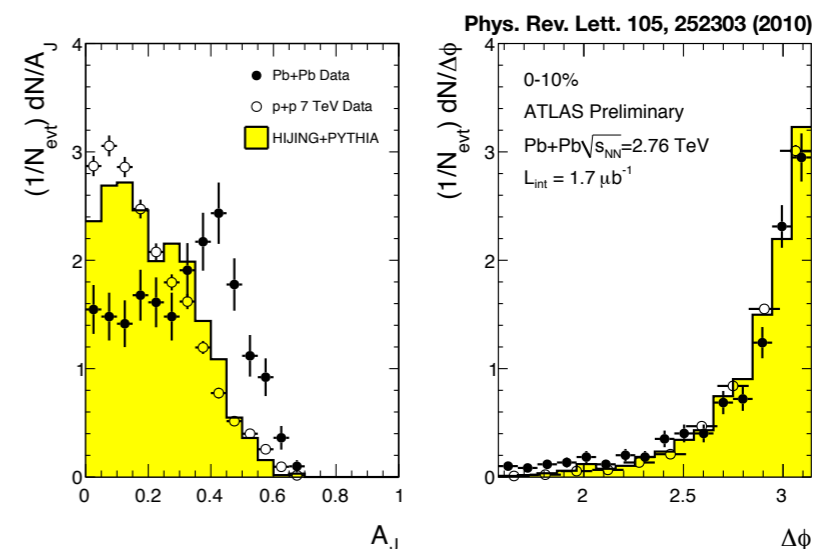
Will LHC make RHIC obsolete?

- **For now, LHC is doing “RHIC physics”**

- High p_T suppression
- Flow (& global variables)
- Quarkonia physics

- **Of course it is already starting to do “LHC physics”**

- Measurements of full jets were published immediately & before RHIC
- Large acceptance correlations
- Heavy flavor already begun in ALICE, and all detectors have large high resolution pixel detectors



- **As RHIC detectors improve, and if the major upgrades happen, we will have the capabilities to address similar physics**

- e.g. heavy quark energy loss using jets: *terra incognita* for both machines!



There have always been (at least) two

80's	AGS	SPS		Light ions (S+Au, Si+Au)
90's	SPS	AGS		Heavy ions (Au+Au, Pb+Pb) Signatures of the QGP
00's	RHIC	SPS		Systematic measurements Heavy & light ions Exploratory energy scans
10's	LHC	RHIC	SPS	High luminosities Jets, Onia, Flavor tagging Precision energy scans

Multiple machines contribute to dynamism of HI physics



Varieties of RHIC responses to the LHC

- **“I, for one, welcome our new LHC overlords”**
 - The LHC will be the ones to discover new phenomena
 - RHIC would then do “LHC physics” at a lower energy density
 - This is an advance or retreat, depending on perspective
- **“Aim for uniqueness” in the RHIC era**
 - Find areas where LHC can not reach and focus there
 - Energy scan in “transition” region, low energy jets
- **The SPS played both roles during RHIC era**
 - New observables applied to lower energy data
 - Energy scans where newer machines couldn’t reach
 - We are now seeing the results of going it alone for a generation (e.g. NA49 vs. STAR)





What do experimentalists want to know?

From PHENIX & STAR decadal plans

- **sPHENIX**

- Physics of rapid thermalization & entropy production
- Degrees of freedom of sQGP (e.g. quasiparticles)?
- Diagnostics of strong coupling (e.g. heavy flavor)
- Mechanisms of energy loss in medium
- Establishment of color screening in medium
- Nuclear wave function: CGC & shadowing

- **STAR**

- Properties of sQGP
- Energy loss mechanisms
- Critical point physics
- Symmetry properties (Chiral Magnetic Effect)
- Exotic particles (e.g. strangelets, glueballs)
- CNM & saturation physics

Shared HI interests in jets, heavy flavor, onia
Shared p/d+A interests in CNM and CGC physics

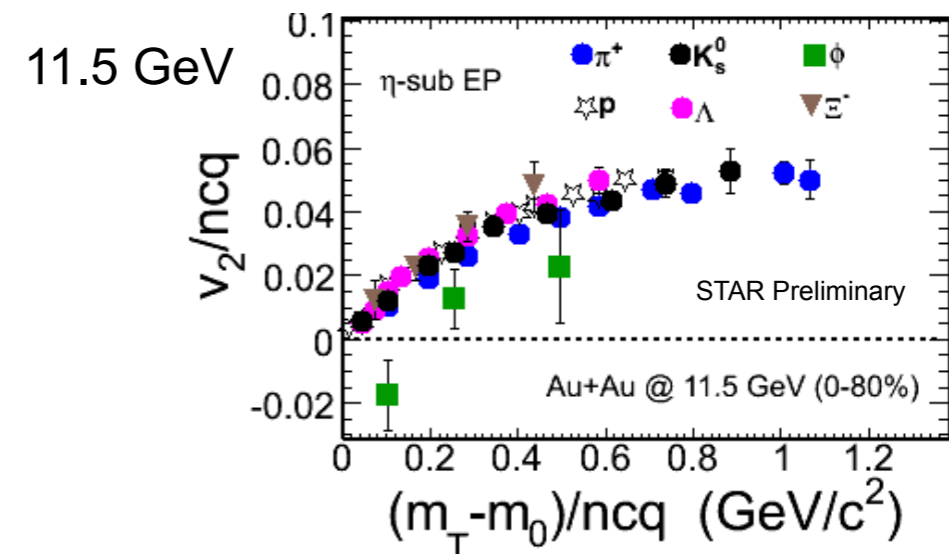
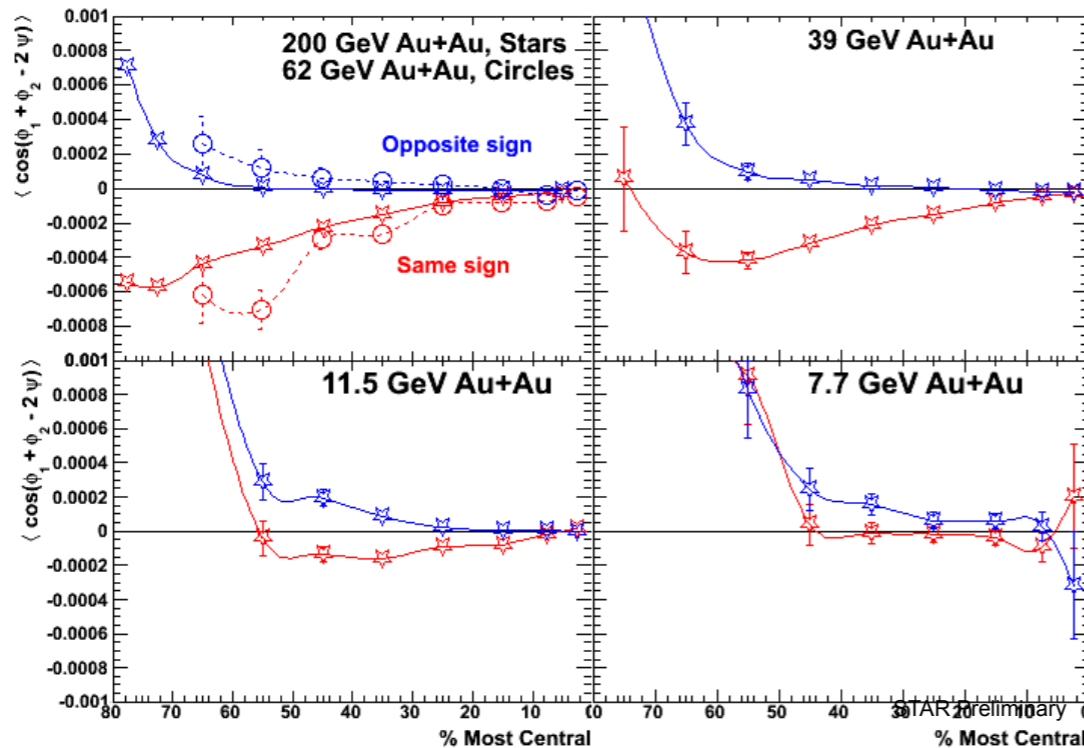
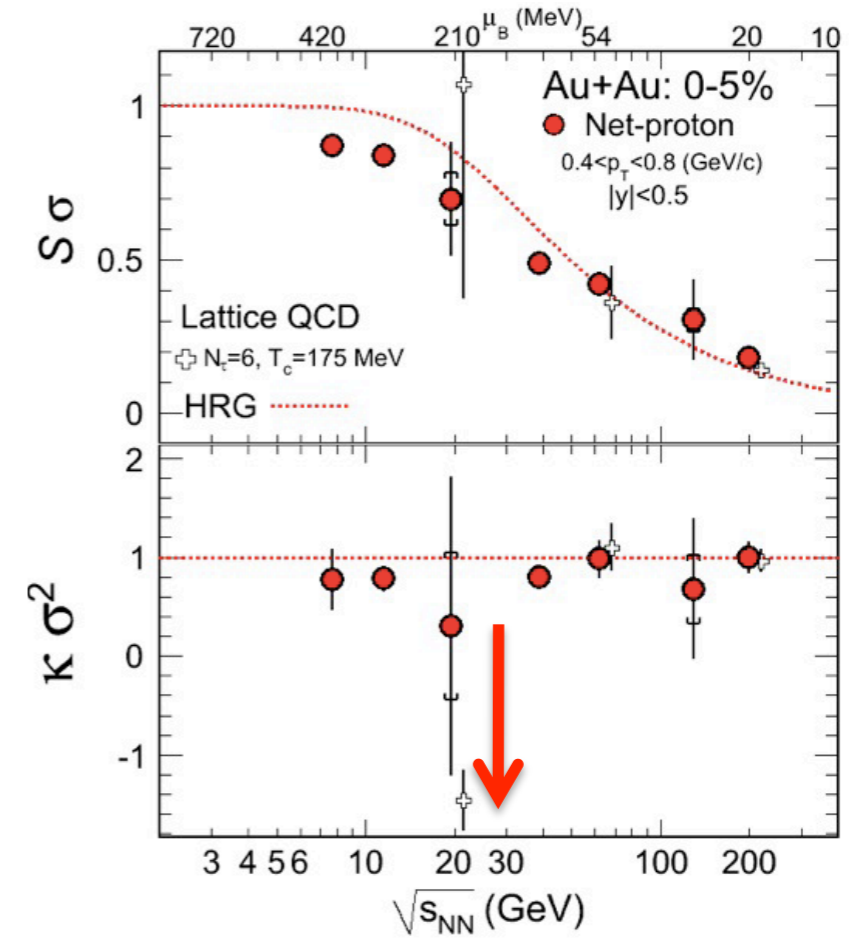
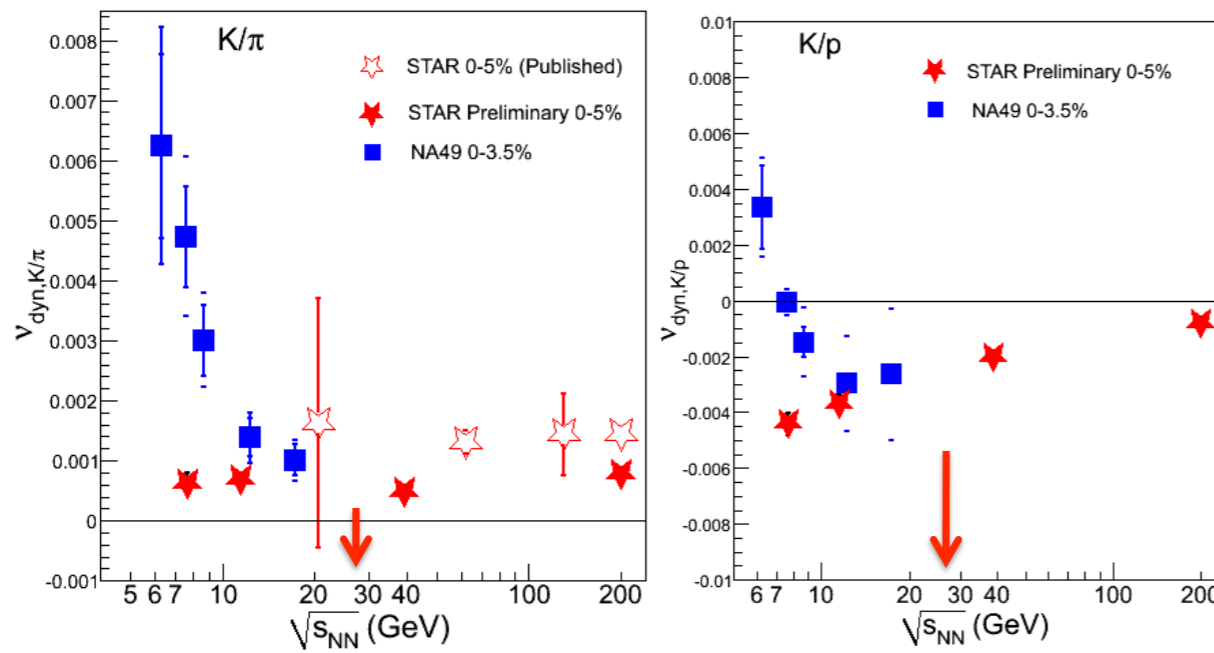
Luminosity physics more of a priority for sPHENIX than STAR
Energy scan physics more of a priority for STAR than PHENIX



The “sweet spot” argument

- **Yesterday, we heard many people suggest the RHIC energy scan sits in a “sweet spot”**
- **The “sweet spot” argument is based on**
 - Strong energy dependence to many observables until $\sim 40\text{-}60$ GeV at RHIC
 - *Possibly non-monotonic behavior in certain variables*
 - Little change in many observables between RHIC and LHC energies
 - *Elliptic flow*
 - *Chiral magnetic effect observables*
- **Clearly requires final results from initial exploratory STAR scan**
- **However, worth a discussion of what is changing?**
 - Is this indication of a phase transition?

Examples



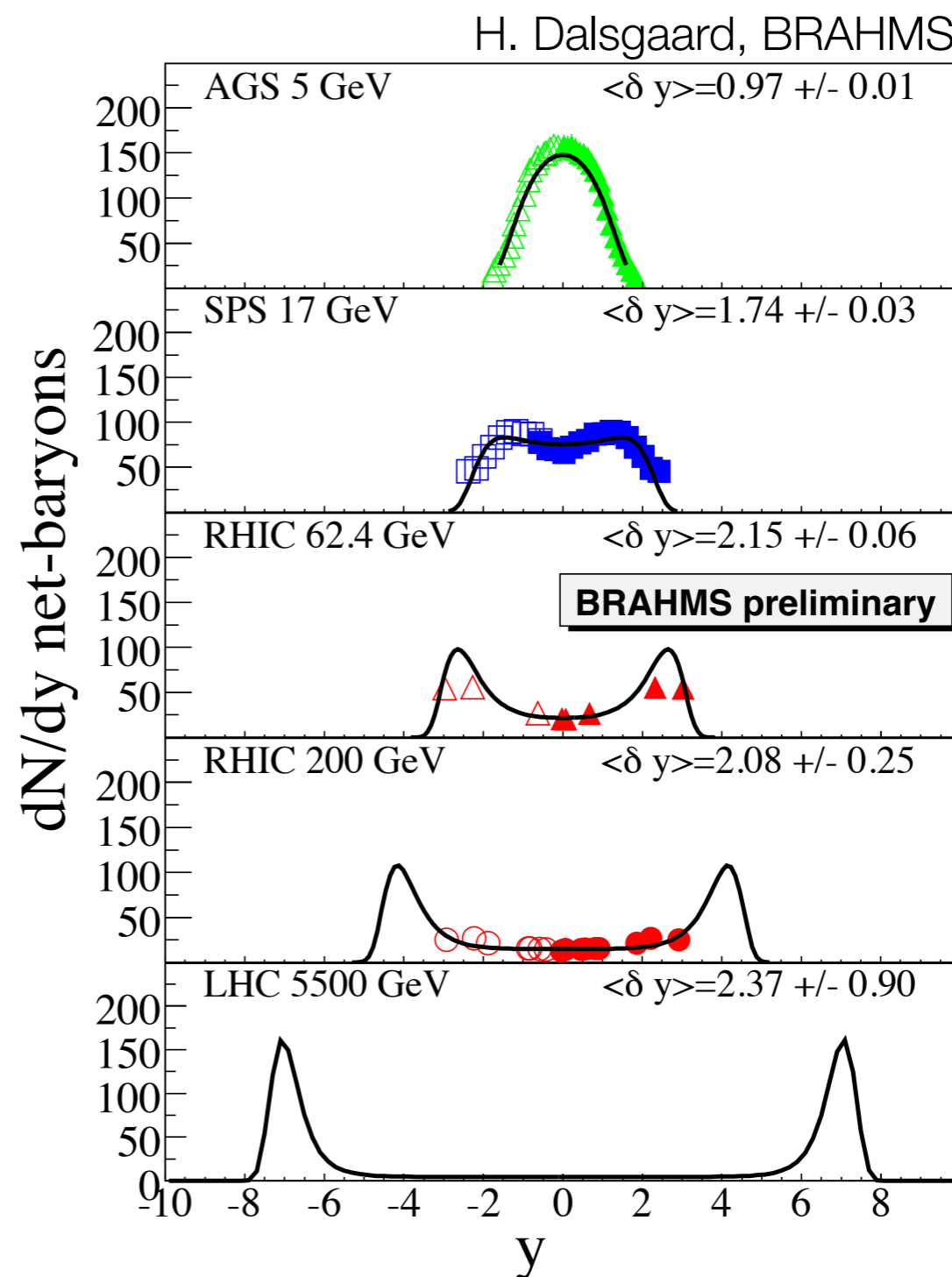


A RHIC plot I haven't seen this week

BRAHMS compiled
 dN/dy of net baryons

At low energy, all of the
baryon number is at the same
rapidity as the fluid

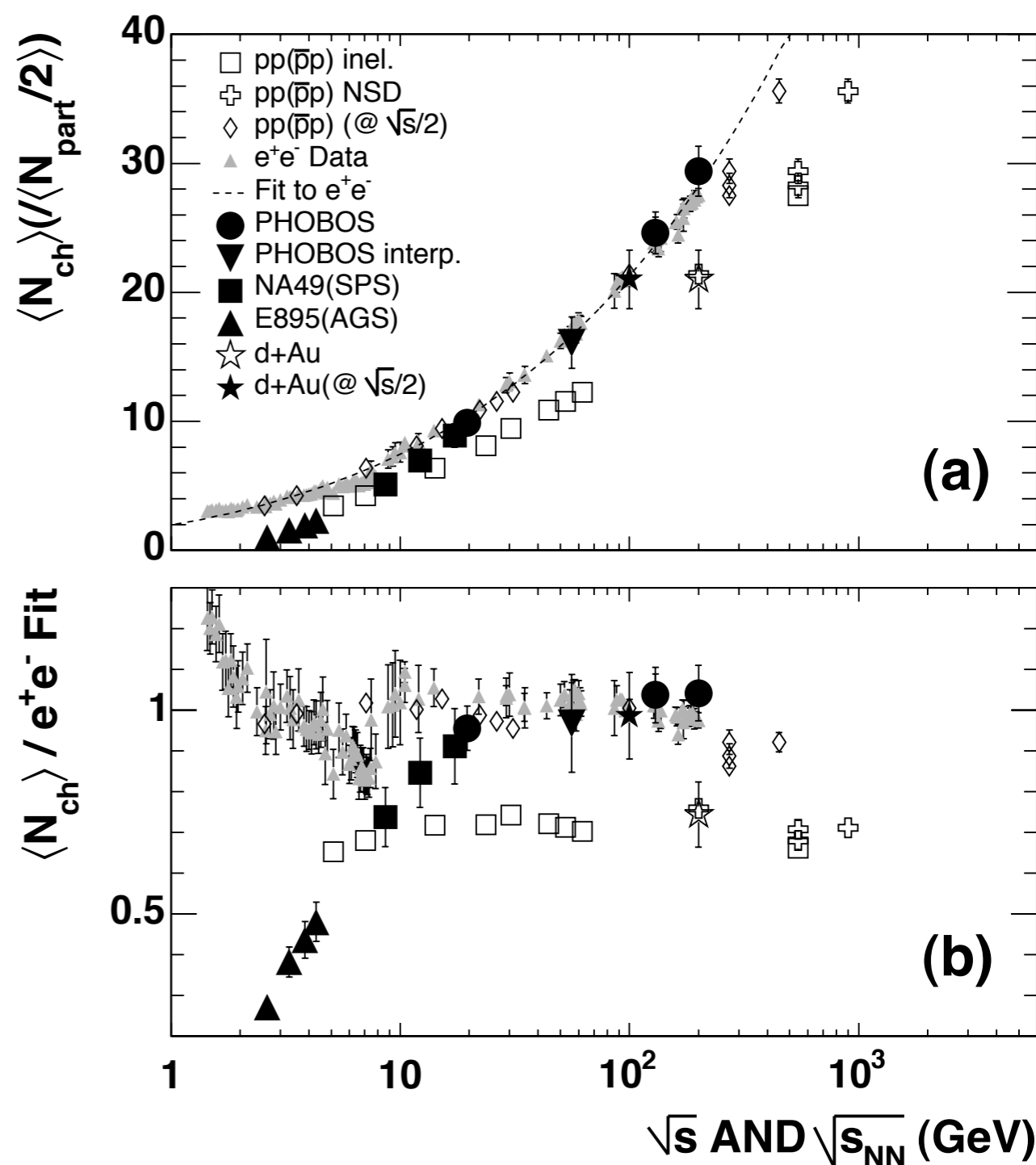
As energy grows, entropy ($s^{1/4}$)
inevitably dominates over
baryon density (N_{part})





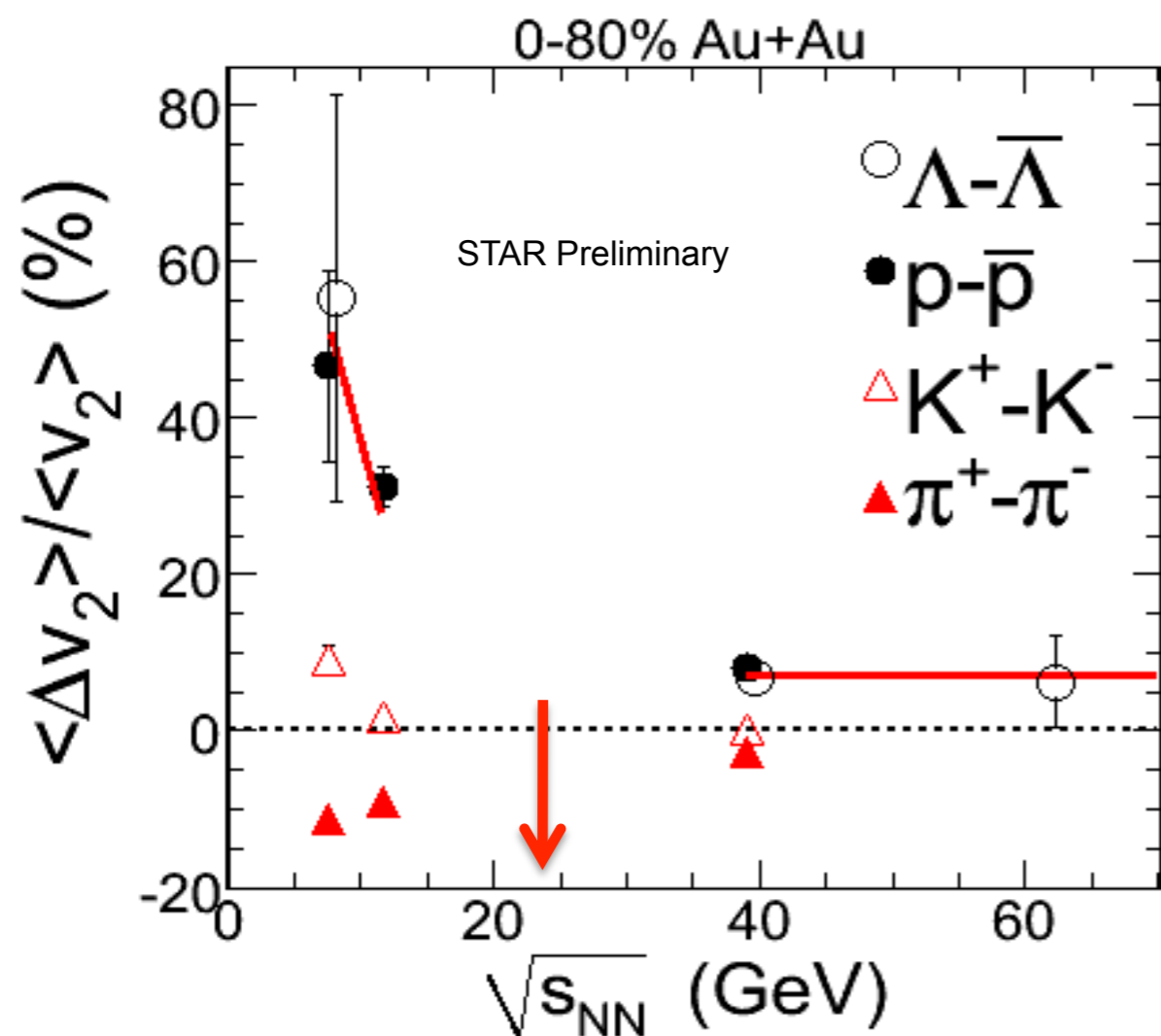
What changes with beam energy?

- **Baryon density must have dynamical consequences**
 - Large mass absorbs kinetic energy
 - Conserved quantity
- **This shows up already even in the total multiplicity (PHOBOS)**
- **It is urgent that hydro experts start to systematically incorporate net baryon density into calculations**
 - This will be another problem for **3D** space-time initialization (similar to Berndt's concern yesterday)

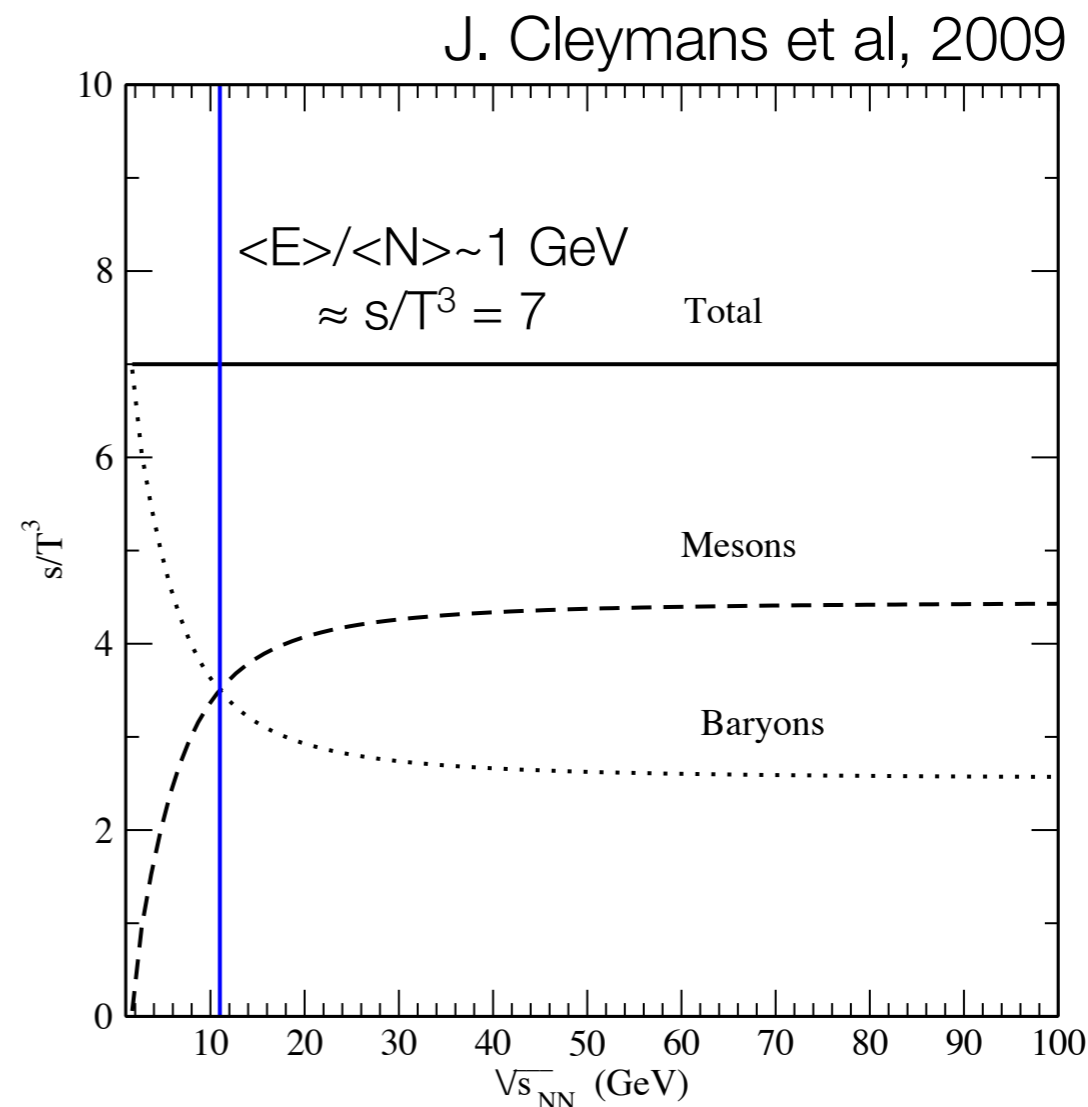




Flow of particles and anti-particles



Clear dominance of baryons
over anti-baryons



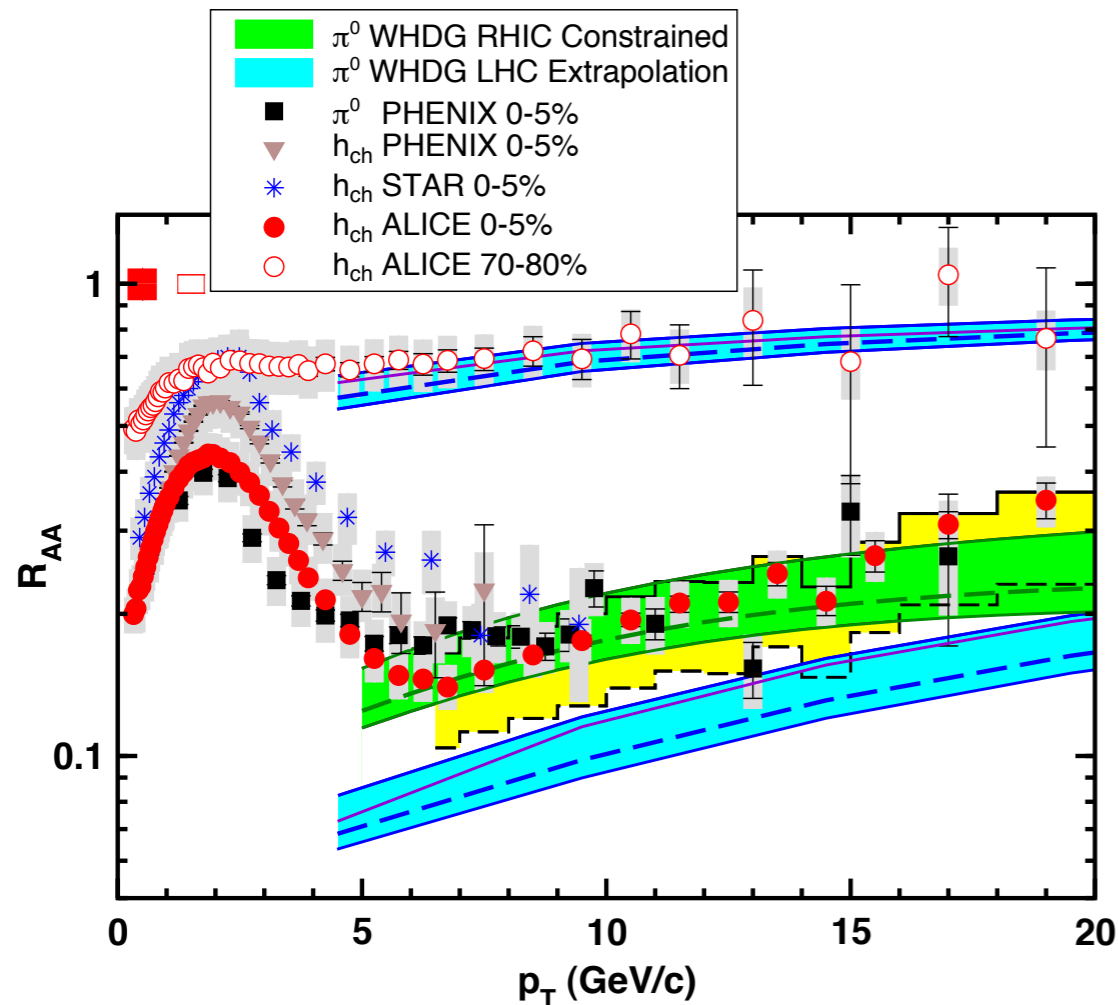
Thermal models show
clear transition between
meson and baryon dominance
at $\sim 10 GeV$



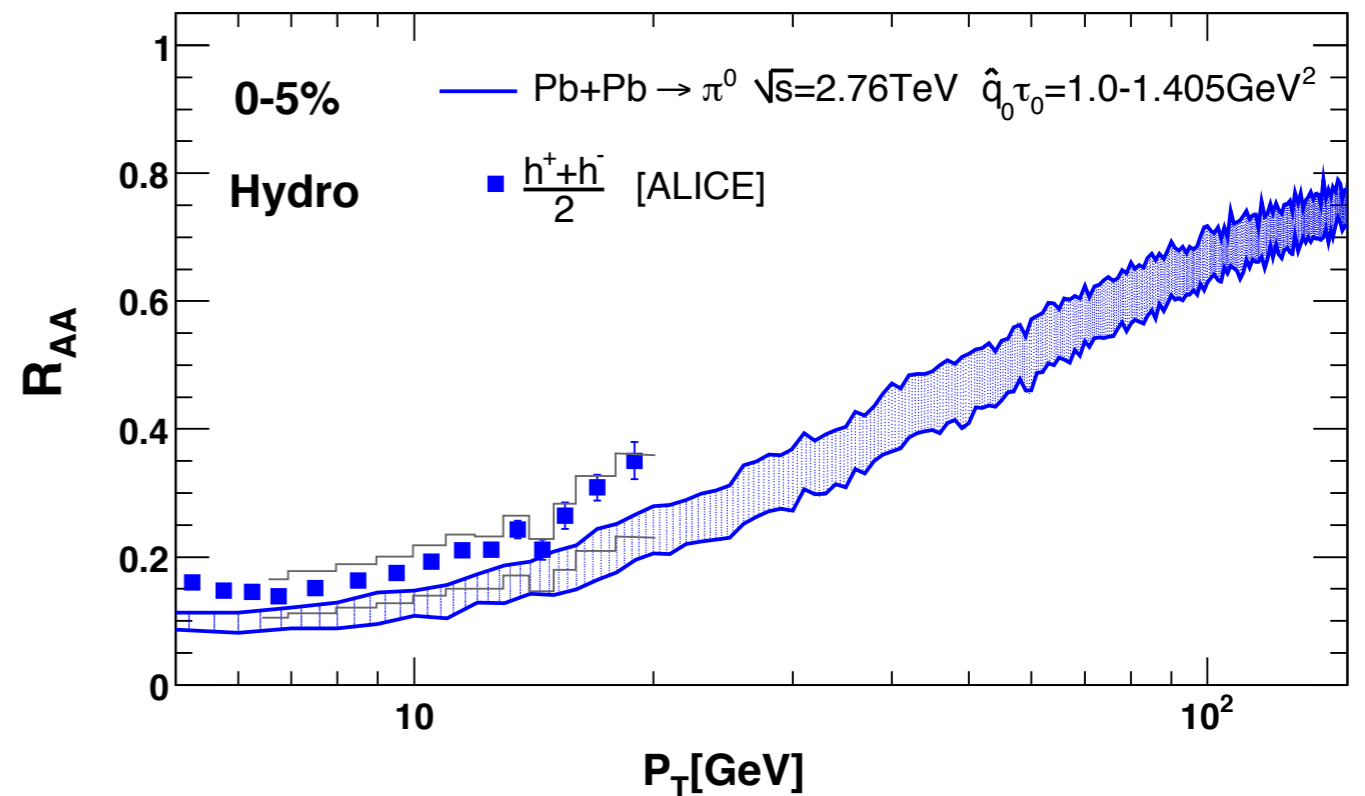
The “lever arm” argument

- **Many new phenomena observed at the LHC may be accessible at RHIC energies, although with more effort**
 - Dijet asymmetries
 - e.g. heavy flavor jets have not been studied at either machine yet
- **Cannot lower energy density in A+A by varying centrality**
 - Multiplicity per participant pair is constant at RHIC & SPS energies, down to very peripheral events
 - One also ends up varying geometry (e.g. flow, but cf. Muller)
- **Lowering beam energy is the most effective way**
 - Esp. to work at same geometric parameters (e.g. eccentricities)
- **Powerful environment to test theoretical models over x14-28 in beam energy, in real time**
 - No more waiting for the future

The “lever arm”, in practice



Horowitz & Gyulassy



Wang & Hirano

RHIC \rightarrow LHC: LHC does not suppress “enough”

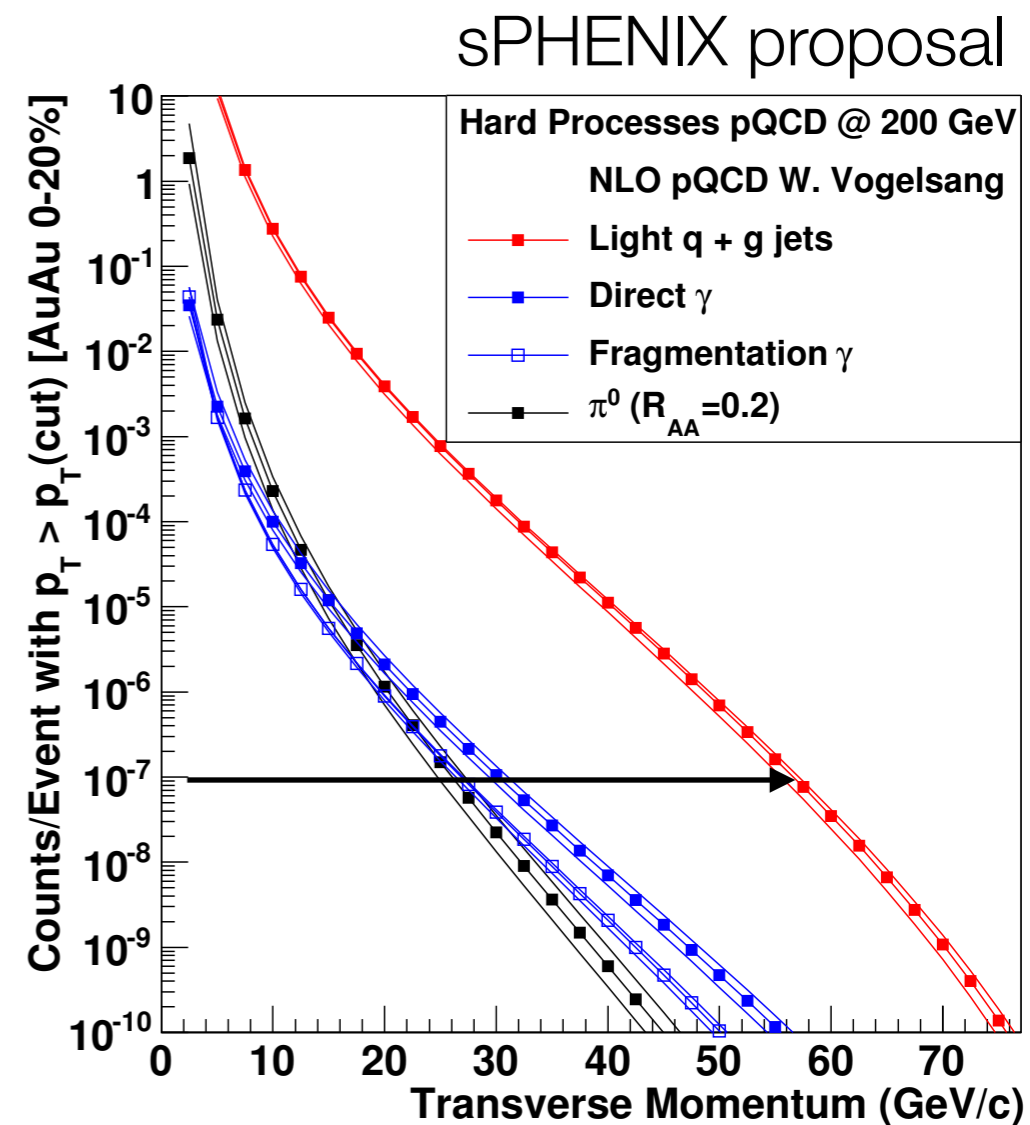
We can expect the opposite in the future:

RHIC should consider being ready to meet the LHC data

LHC Physics at RHIC



- **STAR and sPHENIX are both looking into high p_T physics at RHIC**
 - Fully reconstructed jets, light and heavy flavor
 - Quarkonia
 - Photons and electrons
- **sPHENIX is actively seeking to maximize the p_T reach of RHIC**
 - Huge data rate and selective triggering
- **Better to go for a quality physics measurement as part of “lever arm”**
 - Negotiating a unique RHIC “niche” (e.g. a certain p_T range) here is doomed to fail
 - LHC experiments will push down in p_T if that is where the physics is

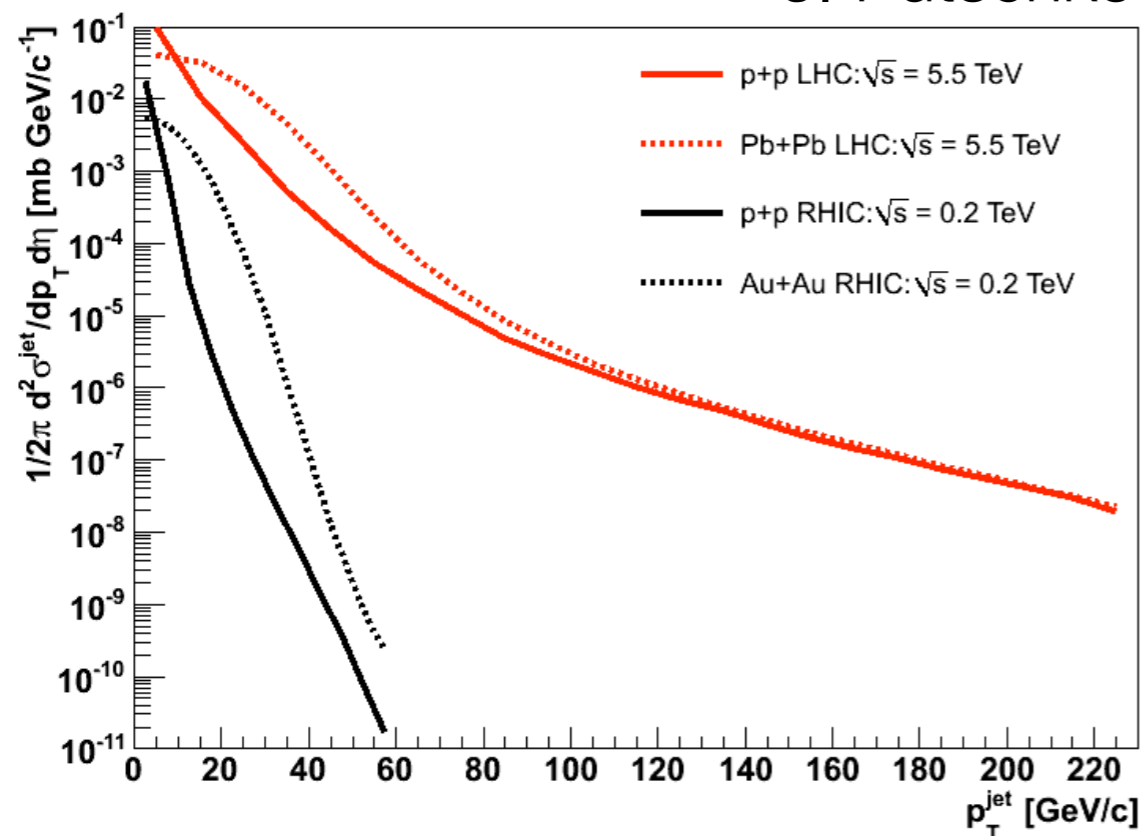


1000 jets above 60 GeV!
1000 photons above 30 GeV!

Jets & fluctuations

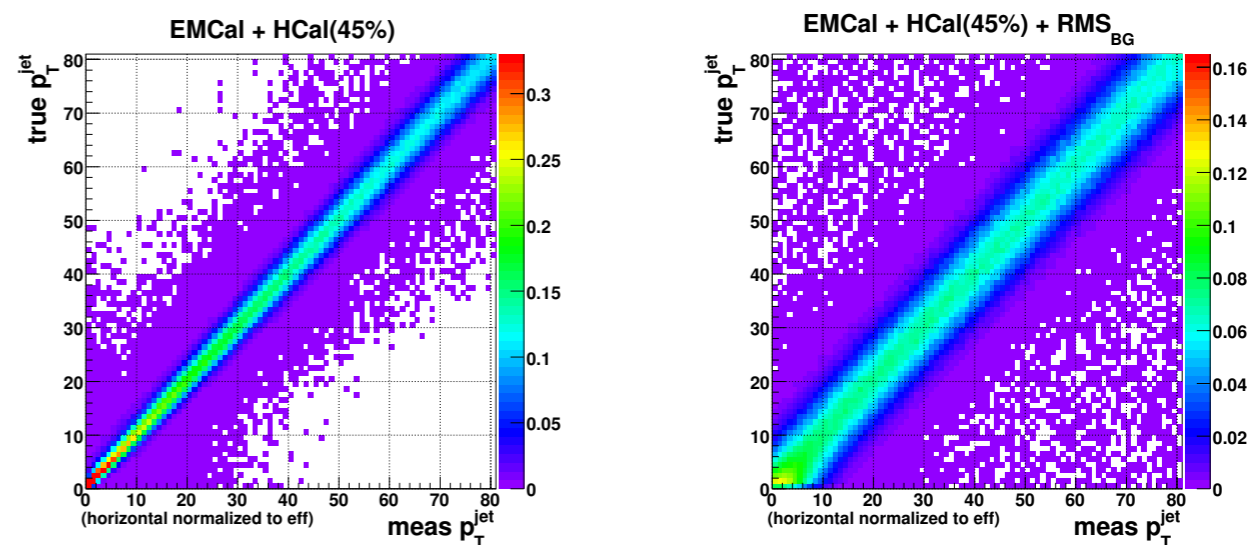


J. Putschke

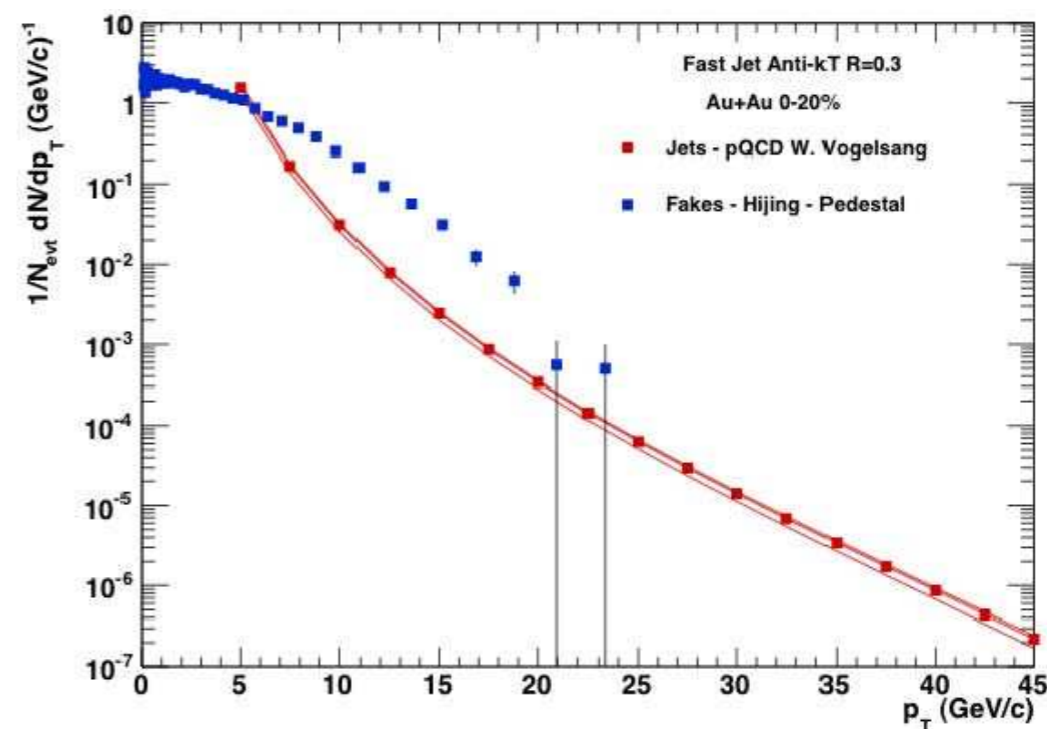


An illustration that fluctuations have to be considered carefully.

Do not be overly pessimistic,
or overly optimistic:
this comes down to quantitative work



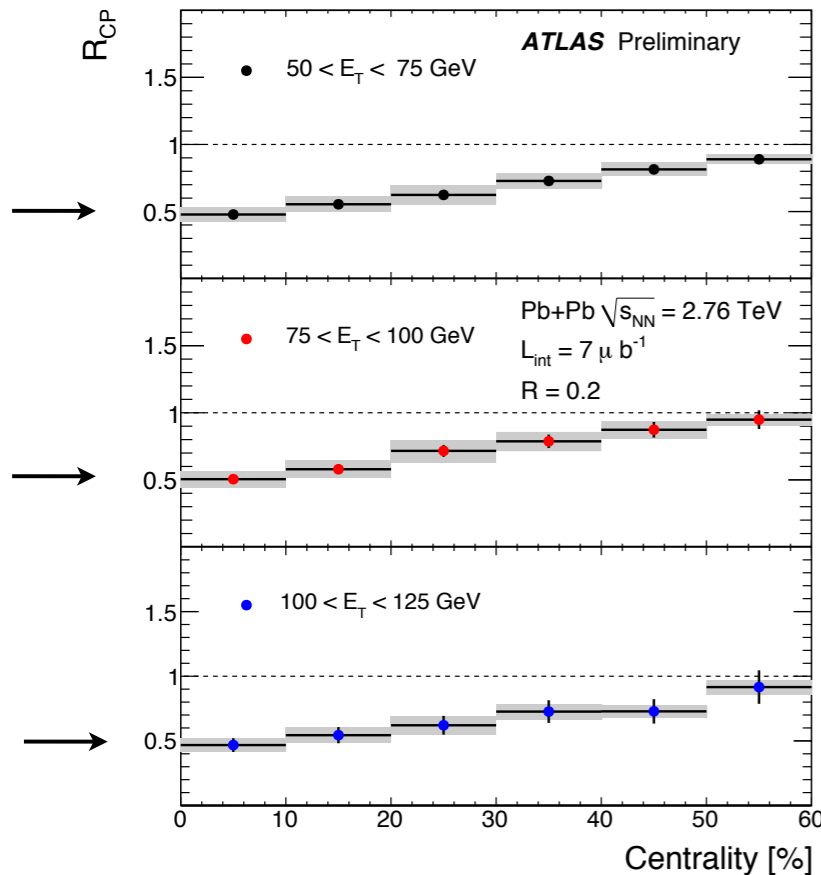
sPHENIX studies have started
looking into this in detail



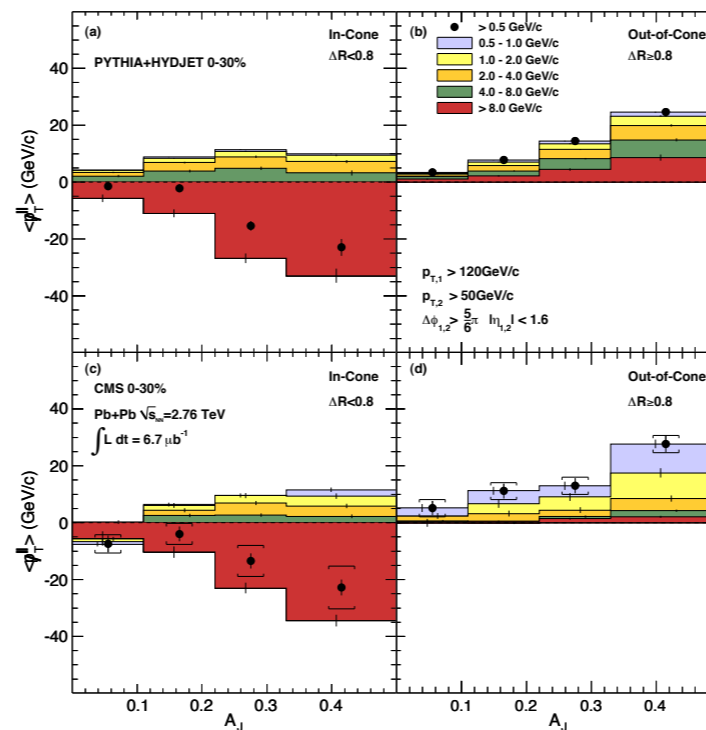
Why **shouldn't** RHIC future look like this?



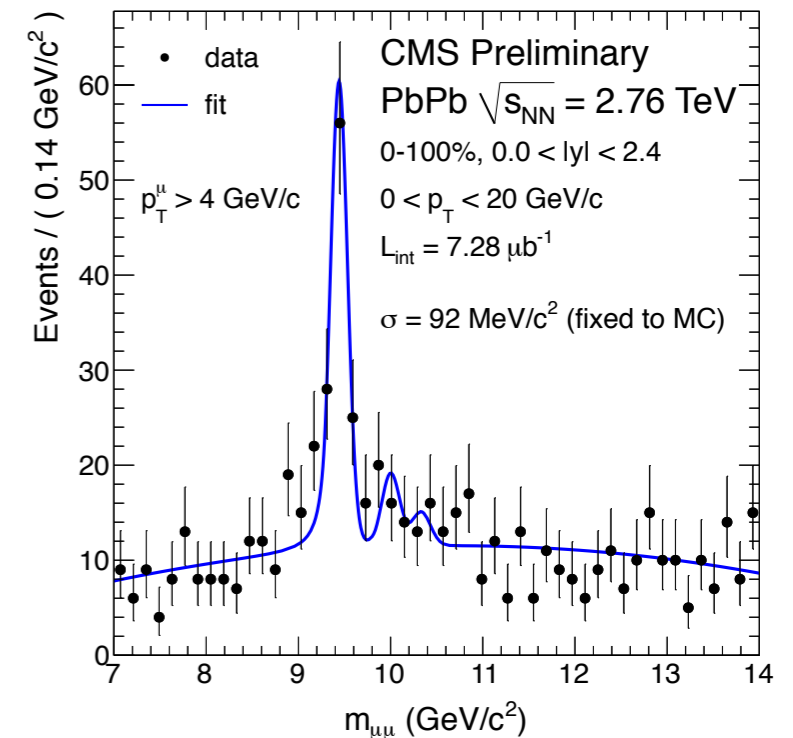
Keep in mind: these are first studies from early days.



Full jet suppression
(incl. heavy flavor)



Detailed fragmentation
studies



Quarkonia physics
(in full range of systems)

We obviously can, with upgraded detectors to maximize use
of RHIC luminosity



Tug of War? Sweet spot vs. Lever arm

We have one machine and 3-4 years before eRHIC

Sweet spot

argument suggests
running at a variety
of low energies

Upgraded STAR
is enough



Lever arm requires
high energy and
highest luminosity

Likely to require
a new detector

Both programs have potentially large scientific impact

Can we do both?

Should we do both?



The big question: which one is worth it?

- **Even the short term is \$1B investment (K. Rajagopal)**
 - And without this, the longer term will not happen
- **Personally, I feel that meeting the future head-on is the better investment**
 - Even as an LHC person, I can admit LHC hasn't really found new phenomena yet: refining our existing view with powerful tools
- **I am also personally nervous that sweet spots don't exist**
 - RHIC put itself on the map from systematic measurements (esp. flow & jet quenching) rather than isolate a single "thing" (peak, jump, feature)
 - Even jet quenching required extensive understanding of context (p+p, centrality, energy dependence)